Combat Zones That See

Multi-Camera Surveillance for Urban Operations

Briefing to Industry

BAA 03-15

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Thomas M. Strat
Information Exploitation Office
tstrat@darpa.mil

Military Challenge

Multi-Camera Surveillance for Urban Operations

- **Urban Combat**
  - Improve situation awareness
  - Extend observation
  - Strengthen force protection
- **Today**
  - Scouts – dangerous
  - HUMINT – scarce and unreliable
  - Overhead – restricted sight lines
  - Video – labor-intensive

- **Ubiquitous vision for military operations in cities**
  - Cities that are not under our control
  - Cities that have been taken, but not fully secured

Less dangerous
More predictable

Functional Capabilities

- **24x7 close-in coverage of city streets and buildings -- automatic video monitoring**

- **Heterogeneous network of video sensors**
  - Objective Force cameras, swarms of OAVs, SOF leave behinds

- **Track all vehicular movement**

- **Scenarios**
  - Force Protection
  - Military Operations in Urban Terrain
    - Continuous Route Reconnaissance
    - Moving Zones of Protection and Pursuit

Challenge Problems

- **Surveillance**
  - High-confidence tracking of an identified vehicle
    - Forward Tracking – Where is he going?
    - Backward Tracking – Where did he come from? How did he get here?
- **Forensics**
  - Find the common element between two incidents
    - By backtracking from both to one or more common ancestors
- **Alerts**
  - Detection of anomalous behavior
    - E.g., the unidentified vehicle speeding away from a scene or following an unusual trajectory

Key Ideas

A processor at every sensor

Eliminate comm bottleneck – no need to transmit video

Track everything that moves -- use tracks to

Calibrate cameras

Learn patterns of activity

Retrieve similar or related events

Persistent sensing

Self-calibration

Normalcy modeling

Motion Pattern Analysis

Find the common elements

Technology

Sensors

Communications

Video Understanding

Motion Pattern Analysis

System Management

Sensor Deployment Options

Surveillance Cameras

Already in place for Force Protection

Power and communications provided

Useful in peacetime

Swarms of OAVs

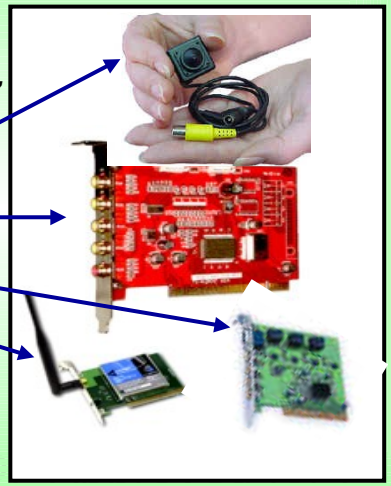
TTO OAVs have all necessary components

- Video camera
- Processor
- GPS
- Comm link
- Power source

- **Mobility -- OAV can perch at desired overwatch position**
- **Power -- 9" OAV has power sufficient for**
  - ~20-minute flight; and
  - ~1 month video collection/processing; and
  - ~2.5 days of transmission interspersed with sensing

Self-Contained Surveillance Device

- **Install cameras as needed**
  - ***Leave behind "stick-ups"***
- **Self Contained Module**
  - ***Camera***
  - ***Event detection***
  - ***Compress/stream***
  - ***Comms (802.11b)***
  - ***COTS components < $250/unit***
- **Battery-powered miniaturized unit**



Video Rope

- **200 cameras per 1000 meters**
- **Cable supplies power, comms, strength**

Communications Options

Communications requirements are modest

- **8 kbps per camera to pass vehicle feature and track information**
- **Occasional surge to 200 kbps to provide live video from a very small number of cameras**

- **Force Protection Configuration to use landline communication**

- **MOUT Configuration to use wireless comms**
  - To support rapid deployment of camera network

This is not a communications program!

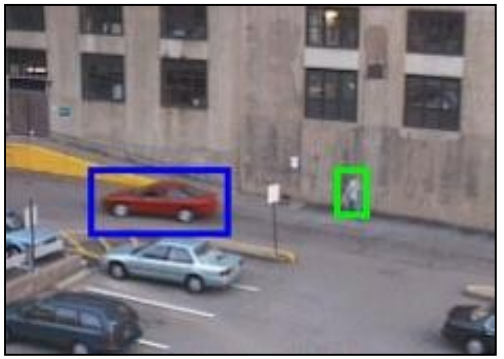
Desire to use COTS comms as much as possible

Video Surveillance: State of the Art

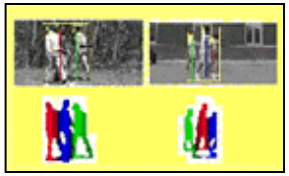
- **Proliferation of cameras**
  - 40 million cameras in use today; 300 million by 2005
  - Cameras and processors and comms are cheap

    $10 + *$140* + *$100* = ***$250* for 24x7 monitoring**

  - Too much manpower to watch the data
  - Video understanding algorithms are improving



- **DARPA VSAM Project (1996 – 1999)**
  - 20 cameras on CMU campus
  - Single-camera tracking
  - Overlapping camera handoff
  - 3D geolocation

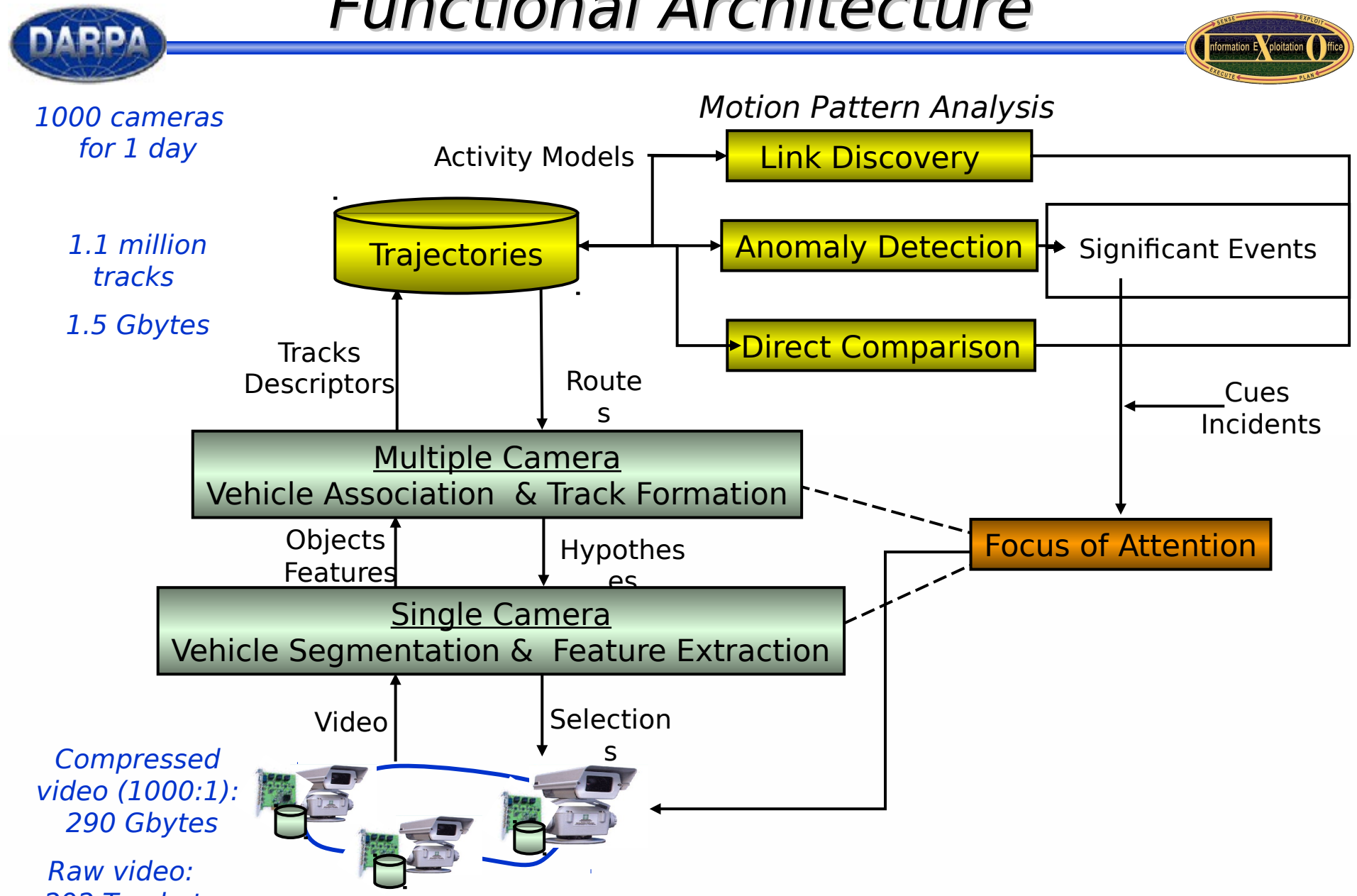


- **DARPA HID (1999 – 2003)**
  - Face and gait recognition

- **COTS**
  - Motion Detection
  - Face Recognition
  - License Plate Reading

Actual image from TolliEx forcer captured at 70mph

Functional Architecture



Multi-Camera Association Test Results

Vehicle association across multiple observations is the key

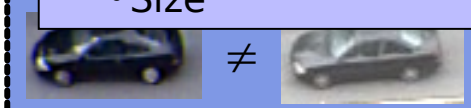
Data Set I: Parking structure rooftop

- 75-meter camera separation
- Vehicles traveling at approx. 20-30 mph
- Traffic density approx. 0.25 vehicles/sec
- Fairly low speed variability
- Unseen ingress/egress point between cameras

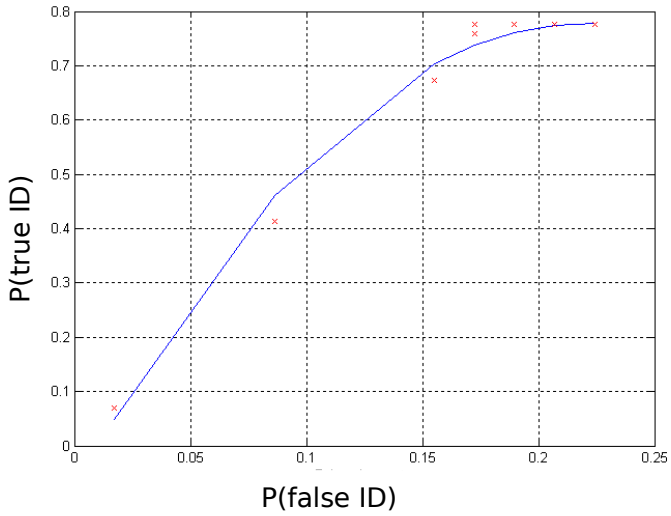
Correct

Using simple observables:

- Predicted vs. actual arrival time
- Color statistics
- Position (e.g. lane)
- Size

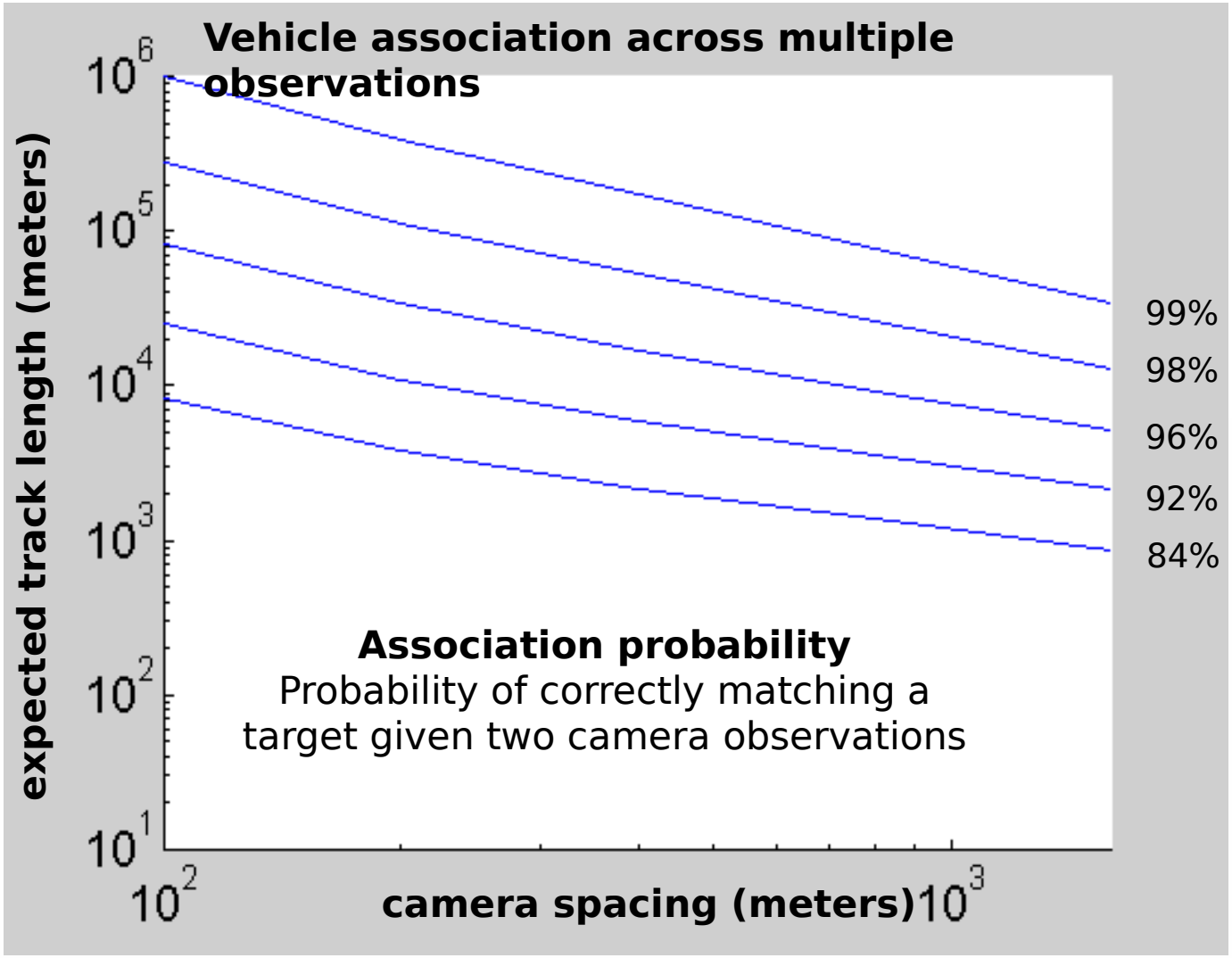


Similar, incorrect



P(true ID) = #correctly matched / #truthed
P(false ID) = # incorrectly matched / #truthed

Performance Analysis



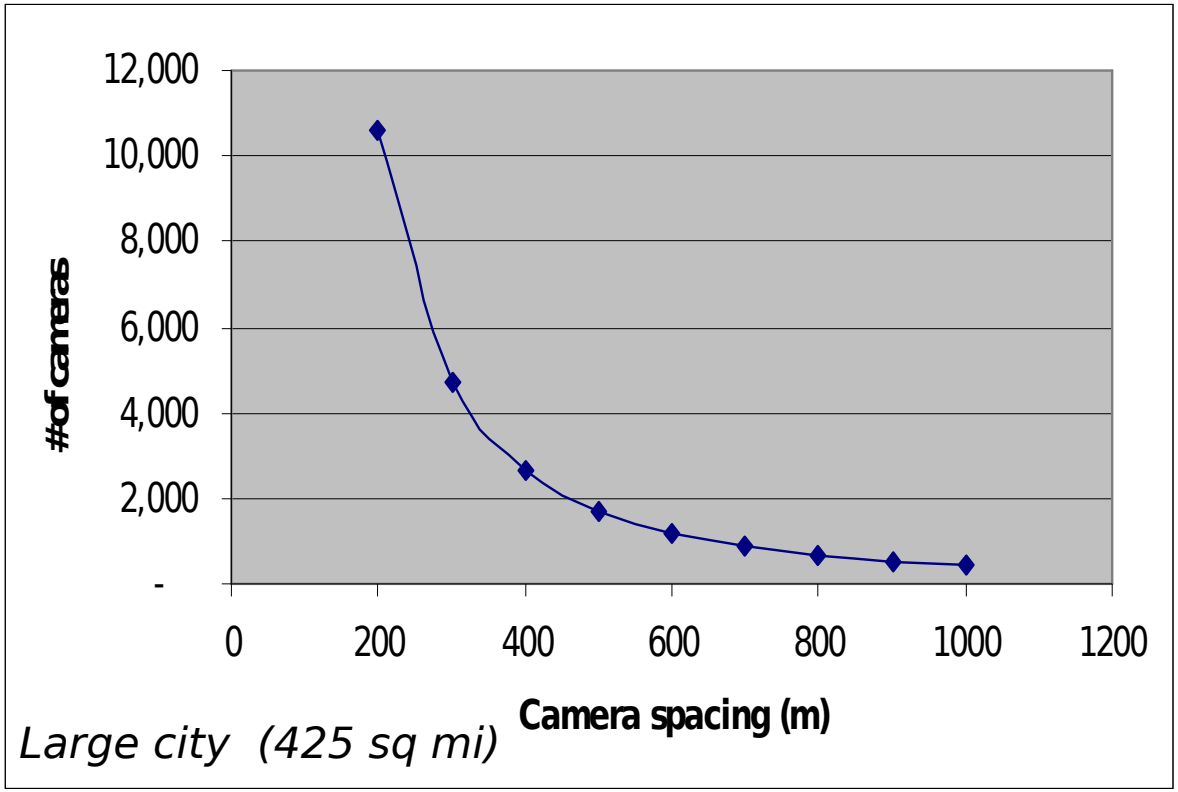
Traffic density:
15 vehicles per minute

Speed uncertainty:
2m/s per 100 meters

Prob(exit/enter/stop)
= 0.01 per 100 meters

How Many Cameras?

Example City	Area km2	Intersections	Overlapping cameras	Cameras 100m apart	Cameras 500m apart	Cameras 1km apart
Large	425	170,000	680,000	42,500	1,700	425
Medium	52	20,800	83,200	5,200	208	52
Small	3	1,200	4,800	300	12	3

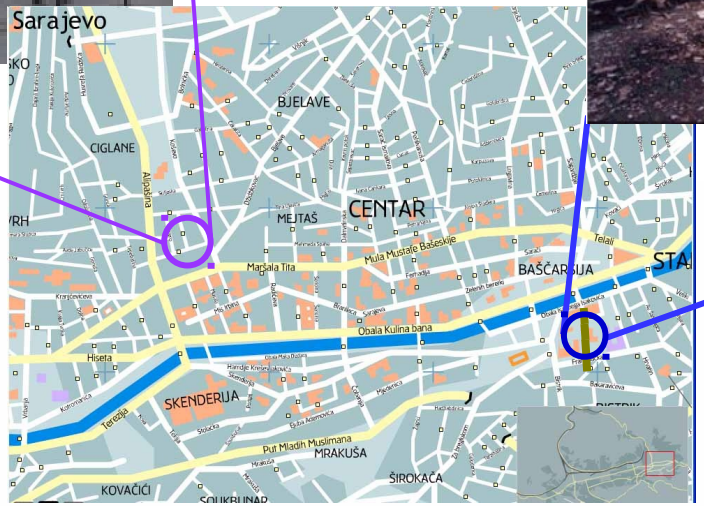


Large city (425 sq mi)

Motion Pattern Analysis: A Sarajevo Scenario

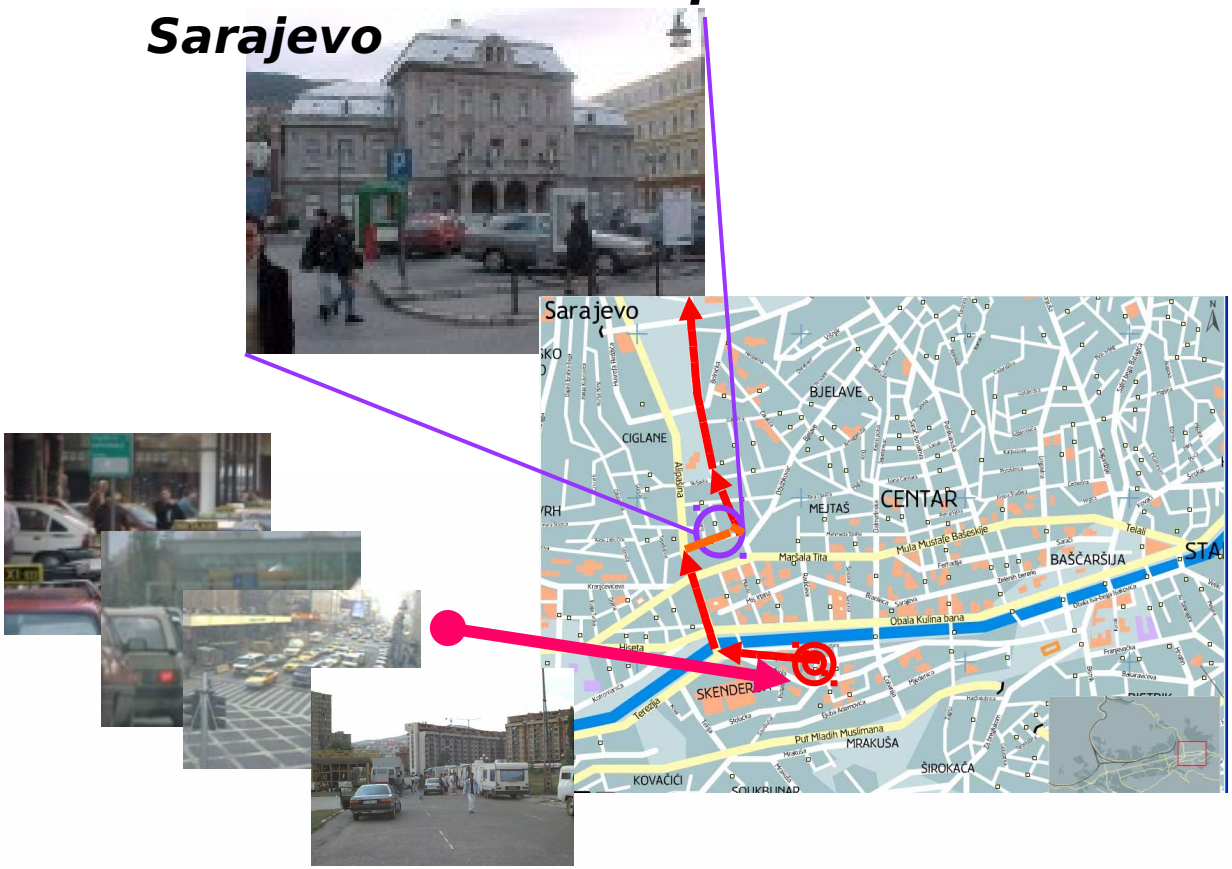
Man shot at Bus Stop in Sarajevo

1 Month Later: Bomb levels disco



Motion Trajectories Prior to Shooting Derived

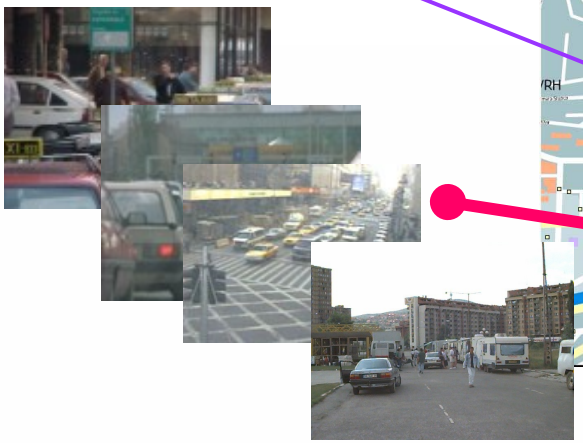
Man shot at Bus Stop in Sarajevo

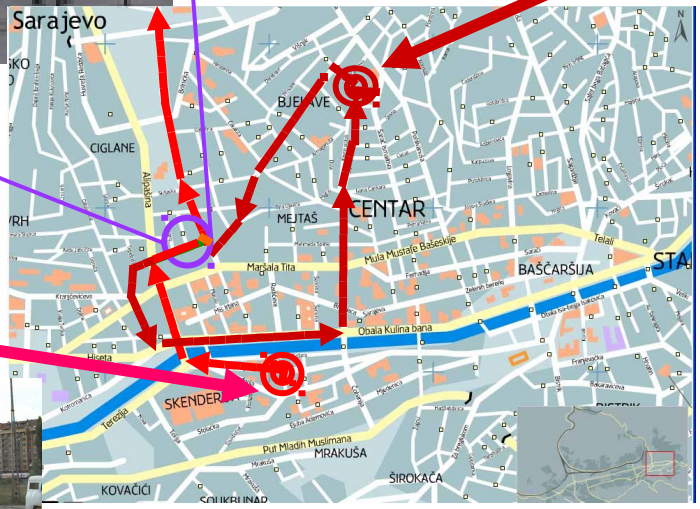


Motion Trajectory X: <Start$_x$> <t$_x$> <seg1> <vel1> <t$_{x+n1}$> <seg2> <vel2> <t$_{x+n2}$> … <Destination$_x$>

All Motion Trajectories & Events Stored

Man shot at Bus Stop in Sarajevo





Trajectory X: <Start$_x$> <t$_x$> <seg1> <vel1> <t$_{x+n1}$> <seg2> <vel2> <tx+n2> ... <Destination$_x$>

Trajectory Y: <Start$_y$> <t$_y$> <seg1> <vel1> <t$_{y+n}$> ... <Dest$_y$>

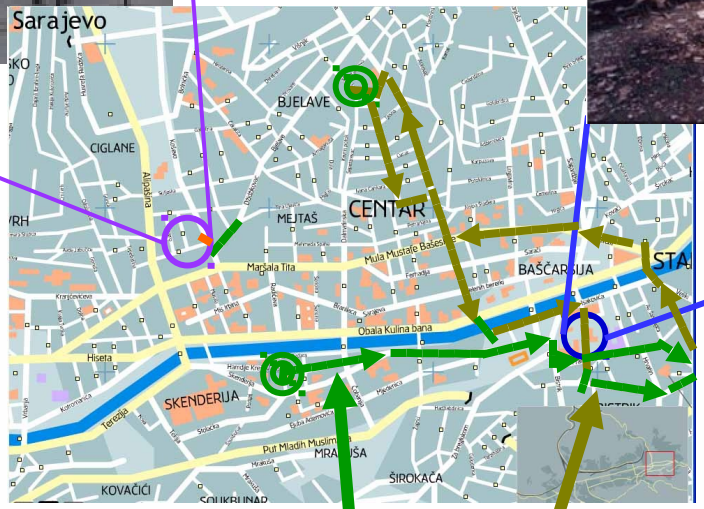
Motion Pattern Data Base:

trajectories, events, trips, compressed clips, object models, ...

1 Month Later: Bomb Levels Disco

Man shot at Bus Stop in Sarajevo

1 Month Later: Bomb levels disco

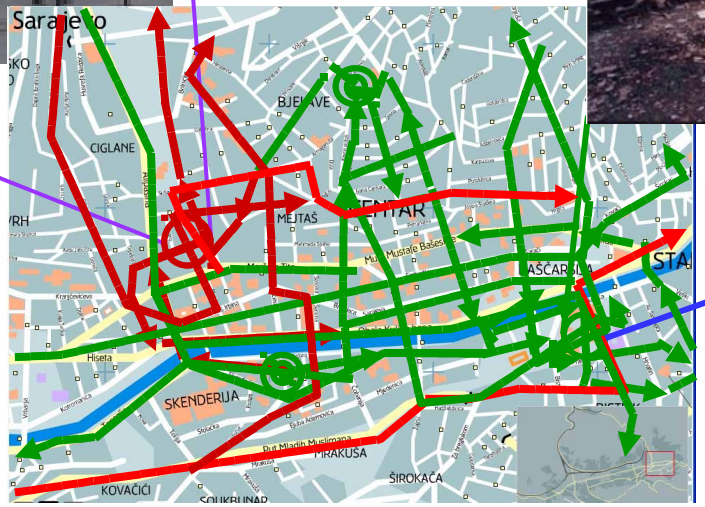


Motion Pattern Analysis Data Base updated with new motion trajectories derived for vehicles seen near the disco prior to blast, Vehicle Descriptions, Events, …

What's Common?

Man shot at Bus Stop in Sarajevo

1 Month Later: Bomb levels disco



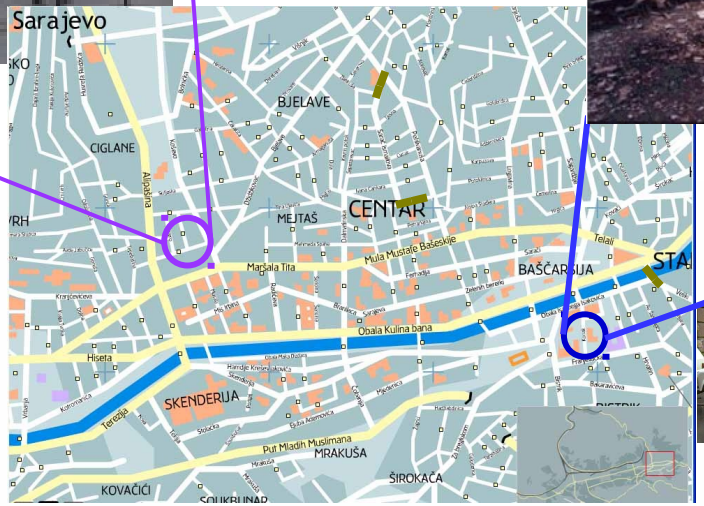
Approx 1000 vehicles passed thru each scene in one hour prior to event.

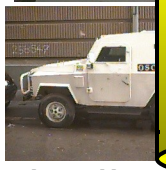
Need to compare 1000 x 1000 trajectories

Search Data Base for Common Vehicles

Man shot at Bus Stop in Sarajevo

1 Month Later: Bomb levels disco





Motion Pattern Data Base:

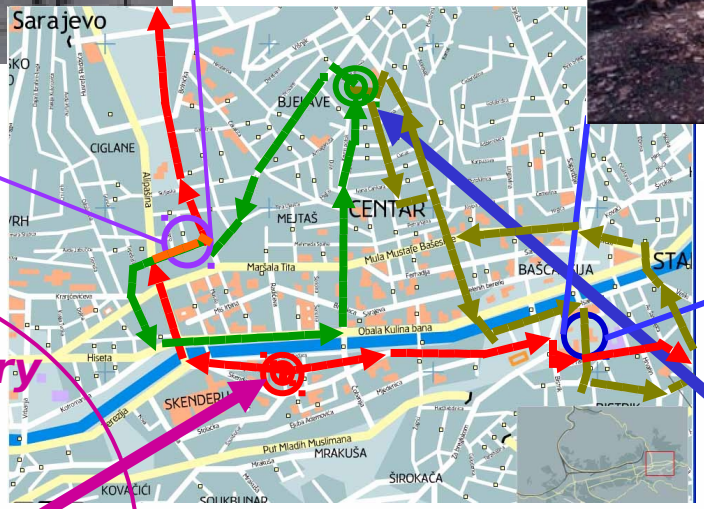
trajectories, events, trips, compressed clips, object models, …

No Vehicles Found in Common!

MPA Searches for Common Elements: 2 Found!

Man shot at Bus Stop in Sarajevo

1 Month Later: Bomb levels disco



Vehicle 1 tracked prior to shooting

#2: Common Trajectory Start Location: suspected Serb resistance cell!

Vehicle 2 seen before bomb blast

 # 1: Shared Start & Destination: Sarajevo Police St

Vehicle 1 tracked prior to shooting

Vehicle 2 seen before bomb blast

Program Emphasis

1. Video Understanding

Vehicle association across cameras without overlapping Fields of View
Vehicle tracking over extended distances with dense traffic
Detecting people entering/exiting vehicles
Self-calibration of rapidly deployed networks

2. Motion Pattern Analysis

Statistical characterization of normal activities
Infer links between seemingly uncorrelated events

Integrate existing capabilities (no new development):

- Video cameras
- License Plate Reading
- Communications

Innovation Is Required

- **The BAA Proposer Information Package**
  - Sets performance goals for a minimal set of functional capabilities
  - Many aspects are unspecified
    - Other visual surveillance tasks
    - Integration with existing/planned sensors and biometric systems
    - Modes of user interaction and Graphical User Interface

- **Successful proposal will**
  - Identify performance goals for objective system
  - Describe initial design -- hardware/software architecture
    - Sensors
    - Communications
    - Video processing
    - Motion pattern analysis
    - System management/control

Application Scenarios

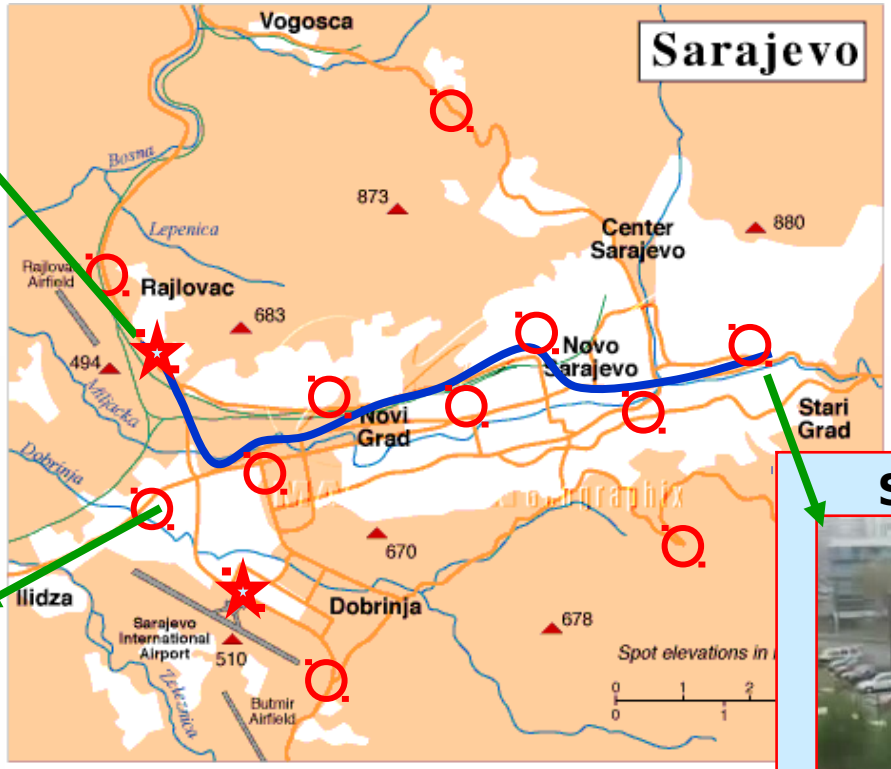
Force Protection

Gate at Compound

Initiate Track
Check with watch list
Issue alert

Traffic Cam

Continue track
Update trajectory



US Facility

Camera locations

Track all vehicles

1000s of cameras
24 x 7 operation

Security Cam

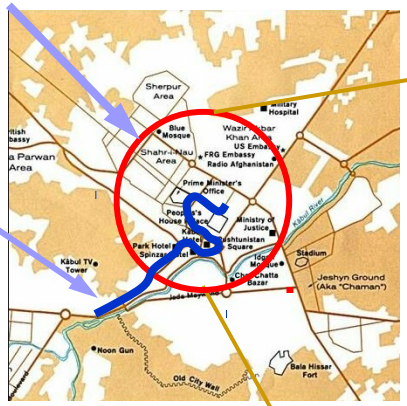
Link person to vehicle
Terminate track

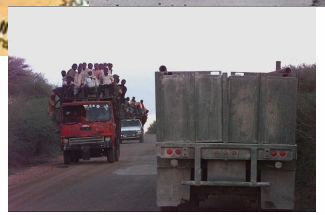
Continuous Route Recon

Planned Ingress

Destination

Current Objective





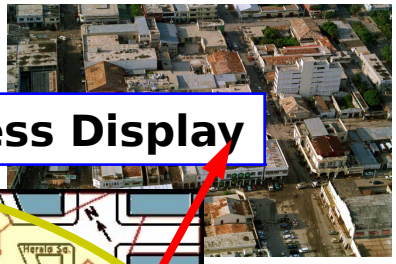
Recon patrol leaves sensors behind;
or
Swarm of OAVs perch along route

Persistently monitor ingress/egress routes

- **Auto detection of individuals, vehicles entering FOV**
- **Tracks initiated on all movers**
- **Display plan view of tracked entities (20 kbps updates)**
- **Full motion video on demand**
- **Significant changes in street characteristics**

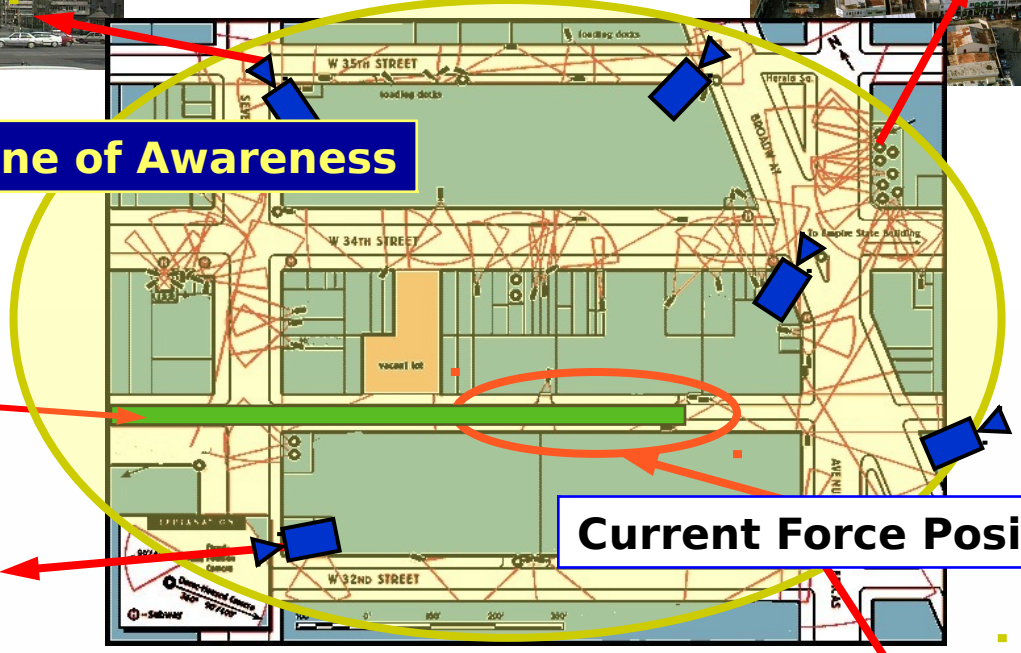
Moving Zone of Protection and Pursuit: Dynamic Plan View of Situation

Continuous Route Recon



Scrolling Situation Awareness Display

Moving Zone of Awareness



Planned Route

Current Force Position

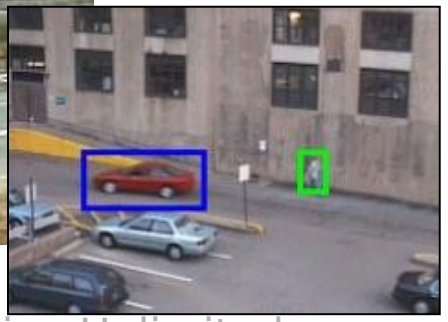
- **Cameras at boundaries of Zone monitored for motion**
- **Alert on auto-detection of individuals, vehicles entering FOV**
- **Tracks initiated on movers, shown as icons on plan view**
- **Designated individuals & vehicles can be tracked**

Programmatics

Combat Zones That See: Program Strategy

- **Start program with Transition**
  - Early deployment to Fort Belvoir, VA
  - Insert currently available capabilities
    - Motion detection
    - License plate reading
  - Evolve
    - Users learn technology;
    - Technologists learn customers' needs

- **Develop new capabilities in parallel**
  - Goals established jointly
    - Detection of individuals, groups, vehicles
    - Multi-camera tracking
    - Distributed control
    - User interface with plan view



- **Inject new modules as they matu**
  - Acceptance test with customer feedback
  - Modify in the Field

System Evolution

	Force Protection (Month 16)	MOUT (Month 28)
Goal	Track vehicles across extended distances using pre-installed cameras	Motion Pattern Analysis of vehicular traffic using rapidly deployed cameras
Go/No-go	Maintain track of 90% of all vehicles for at least 10 km for any 30 minute period of the day Track vehicles forward and backward in time Initiate tracks based on location; license plate # Compare to watch lists Tail suspect vehicles Automate alerts with 10-second video clips within 60 seconds of event: -- vehicle start or stop at selected location -- license plate # match to watch list Store up to 1 million vehicle trajectories and retrieve individual trajectories based on location and appearance within 3 seconds.	Install and operate 100 surveillance cameras within 12 hours Early warning of hostile threats • Alert whenever N vehicles from hostile location approach within X meters of friendly force position Correlation of seemingly unrelated events • Find 90% of common vehicles across 2 one-hour long sets of observations Alert abnormal activities • Report 1% statistically most unusual events
Sensors	>30 COTS surveillance cameras Processor at every camera	>100 rapidly deployable sensor/processor/comm packages

Program Structure

- **BAA 03-15**
  - **No abstract phase**
  - **Proposals Due: 13 May 2003**

  - **A single contractor team, responsible for the entire endeavor**
    - Design, development, video understanding R&D, motion pattern analysis R&D, integration, demonstration, evaluation, installation, maintenance

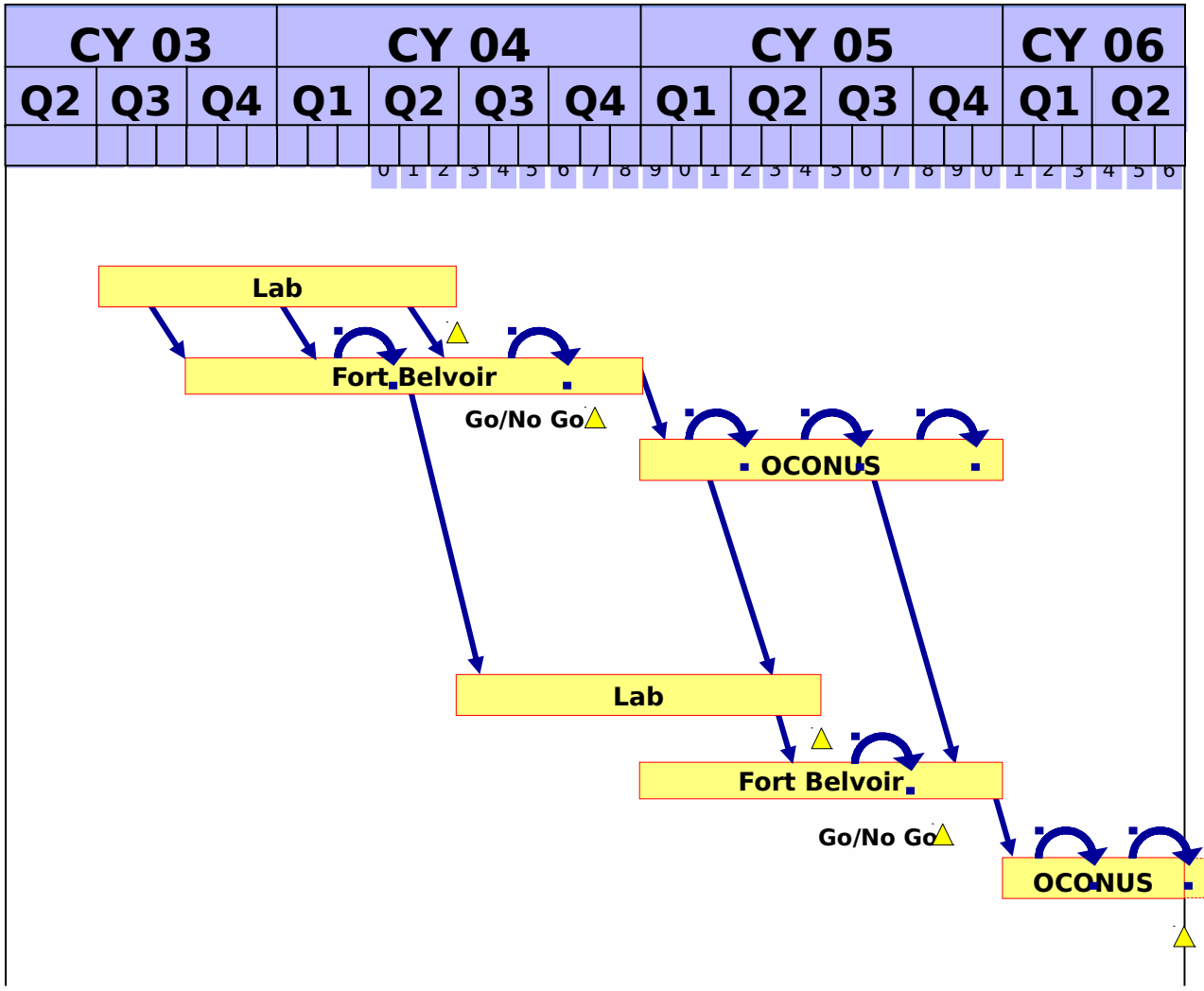
  - **Fort Belvoir**
    - Close cooperation with local officials
    - Use of installed video facilities as convenient
    - In situ experiments to tune and validate
    - Evaluation using live traffic (not staged)

  - **OCONUS**
    - Site to be chosen by government later
    - Close cooperation with supported command
    - Refine Operations Concepts
    - Contractor personnel on-site
    - Rapid tuning in the field

Innovation is required

- Functional capabilities
- Video understanding
- Motion pattern analysis
- Rapid sensor deployment

Schedule



Force Protection Configuration

- Develop Force Protection Config
- Laboratory eval
- Install Force Protection Config at Ft. Belvoir
- l Force Protection Config at Ft. Belvoir
- stall Force Protection Config overseas

MOUT Configuration

- Develop MOUT Config
- Laboratory Evaluation of MOUT Config
- stall MOUT Configuration at Ft Belvoir
- Eval MOUT Configuration at Ft Belvoir
- Install MOUT Configuration overseas
- Program End: Transition to operational use

Payoff: Combat Zones That See

- **Problem: Can't observe the movements of hostile personnel in urban combat zones**
  - Scouts – dangerous
  - HUMINT – scarce and unreliable
  - Overhead – restricted sight lines, limited resources
  - Video – too labor-intensive

- **Solution: 1000s of video cameras – t**

all vehicles
  - Cooperative distributed tracking
  - Motion pattern analysis

- **Reliable source of information affecting combat operations in urban areas**
  - Impossible to obtain by any other means
  - Always on, 24x7 operation

- **Affordable**
  - Replication at hundreds of bases worldwide: < $2M each